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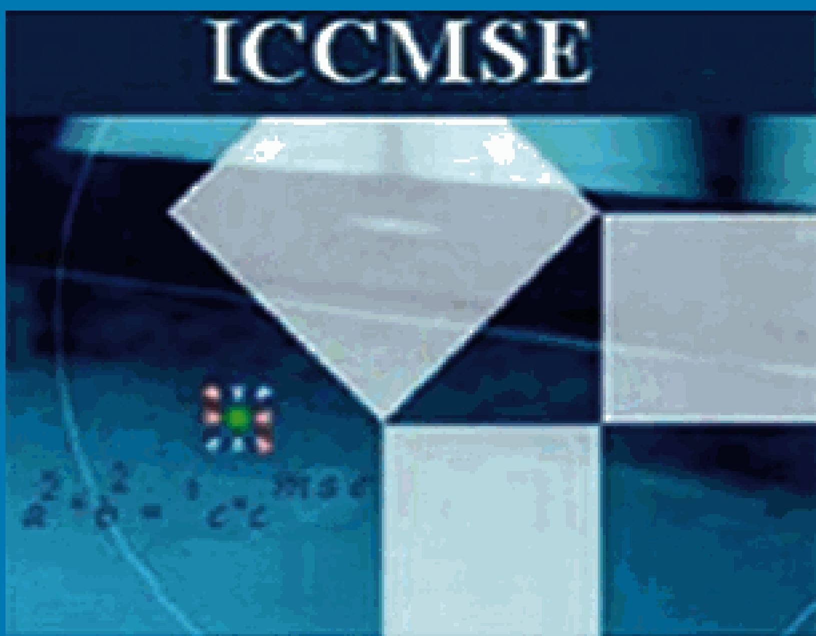

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Digital Image Classification by the Bessel Masks Methodology

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Abstract. Since the evolution of the computer's hardware in the middle of last century, the automatization processes are very productive in fields such as industry, security, engineering and science. In this work a pattern recognition methodology to classified images is presented. Here, the Bessel masks digital image system invariant to position and rotation is utilized to classified gray-scale images. Moreover, by the use of the Fisher's Z distribution the digital system get a 99% confidence level performance.

Keywords: Image processing algorithms, pattern recognition algorithms, Bessel masks, one-dimensional signature, digital image classification method.
PACS: 07.05.Pj; 42.30.Tz; 89.20.Ff.

INTRODUCTION

The pattern recognition algorithms have a broad and varieties applications [1]. These are divided in two categories: local and global features. The principal component analysis (PCA) is a typical example of a global feature technique. On the other hand, the SIFT and SURF algorithms are local features examples, and they are very used in the fingerprints pattern recognition. However, the PCA involves a lot of computational time due to the larger number of arithmetic operations and the performance of SIFT and SURF decays drastically when noise is presented [2]. This paper presents a pattern recognition digital system invariant to position and rotation which is considered into the global feature category. The digital system has shown a very low computational cost time and an excellent performance, it obtained a confidence level of 99% in the classification of 7,560 problem images even they presents non-homogeneous illumination and noise.

THE DIGITAL SYSTEM

The digital system works with $n \times n$ gray-scale images, only. For a given image I, (x,y) represents a pixel of the image and $I(x,y)$ its corresponding intensity value, $x,y \in \{1,\ldots,n\}$ and the centered-pixel (c_x,c_x) of the image is given by

$$c_x = \begin{cases} \frac{n}{2}+1, & \text{if } n \text{ is even,} \\ \lfloor \frac{n}{2} \rfloor + 1, & \text{if } n \text{ is odd,} \end{cases} \tag{1}$$

here $\lfloor z \rfloor$ rounds z to the nearest integer towards $-\infty$. The shift invariance is achieved in an easy manner by the modulus of the Fourier transform of the image, that is, $|FT(I)|$.

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The Bessel Mask

To obtain the rotational invariance, a binary rings mask is build using the ratio of the Bessel function of first kind and first order by its argument, that is

$$y(x) = \begin{cases} \frac{J_1(x-c_x)}{x-c_x}, & \text{if } x \neq c_x, \\ 1, & \text{if } x = c_x, \end{cases} \tag{2}$$

where $x = 1, \ldots, n$. Base on equation (2) we can build the following binary function

$$Z(x) = \begin{cases} 1, & \text{si } y(x) > 0, \\ 0, & \text{si } y(x) \leq 0. \end{cases} \tag{3}$$

Finally, taking the vertical axis $x = c_x$ as the rotation axis, the $Z(x)$ function is rotated 360 degrees to obtain concentric cylinders of height one, different widths and centered in (c_x, c_x) pixel. Taking a cross-section, we built the Bessel binary rings mask (Figure 1c) [3, 4].

The Signature of the Image

For a given image called I, for example Figure 1a, the first step to obtain its one-dimensional signatures is filter the $|FT(I)|$ (Figure 1b) by the Bessel mask, hereafter named B (Figure 1c), that is,

$$H = B * |FT(I)|, \tag{4}$$

the $*$ means the point to point multiplication of both images. Figure 1d shows the H image for Figure 1a. After that, the rings in H are numbered from the center toward out-side to get the set

$$index = \{ring\ index \in \bar{n}\}, \tag{5}$$

where $\bar{n} = \{1, \ldots, n\}$. Then, the addition of the intensity values in each ring are computed to generate the function

$$\begin{aligned} signature &= index \rightarrow A \subset \mathbb{R}, \\ signature(ring\ index) &= \sum H, \text{ if } H(x,y) \text{ belongs to } ring\ index. \end{aligned} \tag{6}$$

Figure 1e shows the one-dimensional signature associated to Figure 1a.

THE CLASSIFICATION METHODOLOGY

In the pattern recognition step, first of all, it is set the signatures for the target T, called S_T. Then, the autocorrelation of S_T is computed as

$$C_L(S_T) = FT^{-1}\left\{|FT(S_T)|\, e^{i\varphi}\, |FT(S_T)|\, e^{-i\varphi}\right\}, \tag{7}$$

where φ is the phase of the Fourier transform of the signature S_T. Then, the signature is weighted by

$$\eta_T = max\left\{|C_L(S_T)|\right\}, \tag{8}$$

to obtain that

$$\tilde{S}_T = \eta_T S_T. \tag{9}$$

To determine the pattern in the problem image (PI), as a first step its weighted signature is obtained, lets call it $\tilde{S}_P$. The next step is compute the correlation of $\tilde{S}_T$ and $\tilde{S}_P$ as

$$C_L(\tilde{S}_T, \tilde{S}_P) = FT^{-1}\left\{|FT(\tilde{S}_P)|\, e^{i\phi}\, |FT(\tilde{S}_T)|\, e^{-i\varphi}\right\}, \tag{10}$$

here ϕ is the phase of the Fourier transform of the signature $\tilde{S}_P$. If the $max\left\{C_L(\tilde{S}_T, \tilde{S}_P)\right\}$ is similar to the $max\left\{|C_L(\tilde{S}_T)|\right\}$ then, the PI is T, on the other hand it is another image.

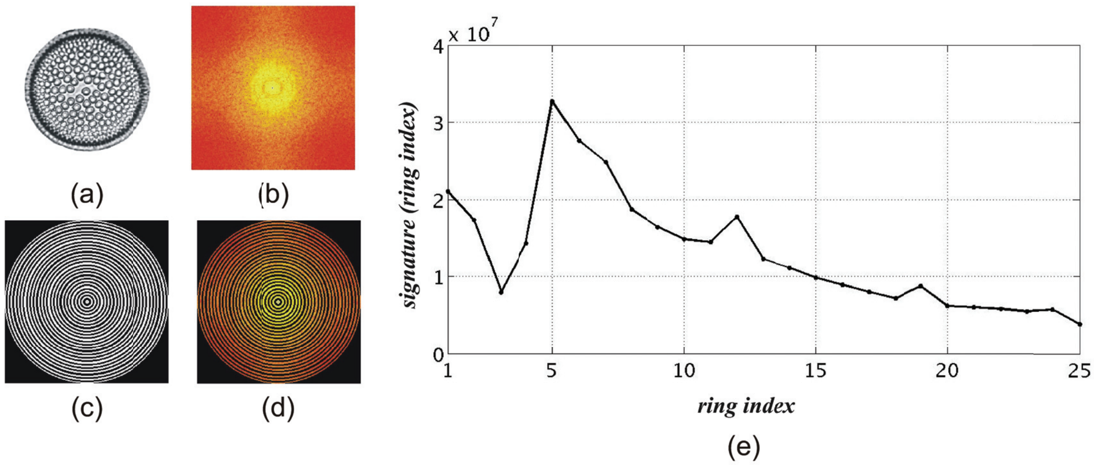

FIGURE 1. (a) I: *Actinocyclus ingens - Rattray*. (b) $|FT(I)|$. (c) B: Bessel mask. (d) $H = B * |FT(I)|$, the $*$ means the point to point multiplication of the images. (e) Signature of Figure 1a.

To do the classification, a reference images database should be establish, $\beta_{IR} = \left\{IR_j \in M_{n\times n}\right\}$. Because the IR_j image, for example Figure 1a, could be presented in the plane in any rotational angle, it was rotated 360° with $\Delta\theta = 1°$. Then, their corresponding weighted signatures are obtained, called $\tilde{S}_{P_\theta}$. Here, the $max\left\{|C_L(\tilde{S}_{IR_j})|\right\}$ and the $max\left\{C_L(\tilde{S}_{IR_j}, \tilde{S}_{P_\theta})\right\}$ are not equal due to the sawtooth-noise generated when the images were rotated. Moreover, those 360 correlation values do not have a normal distribution, thus, the Fisher's Z-distribution is used to establish the confidence intervals. Because of the use the Fisher distribution, first of all, the data should be normalized, then

$$r_j^\theta = \frac{max\left\{C_L(\tilde{S}_{IR_j}, \tilde{S}_{P_\theta})\right\}}{(N-1)\sigma_{IR_j}\sigma_{P_\theta}}, \tag{11}$$

where N is the cardinality for the domain of $\tilde{S}_{IR_j}$. σ_{IR_j} and σ_{P_θ} are the standard deviation of $\tilde{S}_{IR_j}$ and $\tilde{S}_{P_\theta}$, respectively. The Fisher Z-value to r_j^θ is given by

$$Z_j^\theta = 1.1513\ ln\left(\frac{1+r_j^\theta}{1-r_j^\theta}\right). \tag{12}$$

The confidence interval of 95% for the mean of Z_j^θ are set by,

$$\left[Z_-^{j,\theta}, Z_+^{j,\theta}\right] = \left[Z_j^\theta - 1.96\sigma_Z, Z_j^\theta + 1.96\sigma_Z\right], \tag{13}$$

using a standard deviation of $\sigma_Z = \frac{1}{\sqrt{n-3}}$, where n is the size of the sample, in this case $n = 360$. For a 99%, the confidence interval for the mean of Z_j^θ is

$$\left[Z_-^{j,\theta}, Z_+^{j,\theta}\right] = \left[Z_j^\theta - 2.575\sigma_Z, Z_j^\theta + 2.575\sigma_Z\right]. \tag{14}$$

Finally, the confidence interval for a given r_j^θ is transformed by

$$\rho_-^{j,\theta} = \frac{e^{2Z_-^{j,\theta}}-1}{e^{2Z_-^{j,\theta}}+1}, \qquad \rho_+^{j,\theta} = \frac{e^{2Z_+^{j,\theta}}-1}{e^{2Z_+^{j,\theta}}+1}, \tag{15}$$

to set the confidence interval $\rho_-^{j,\theta} \le \rho_j^\theta \le \rho_+^{j,\theta}$, where ρ_j^θ is the true correlation coefficient.

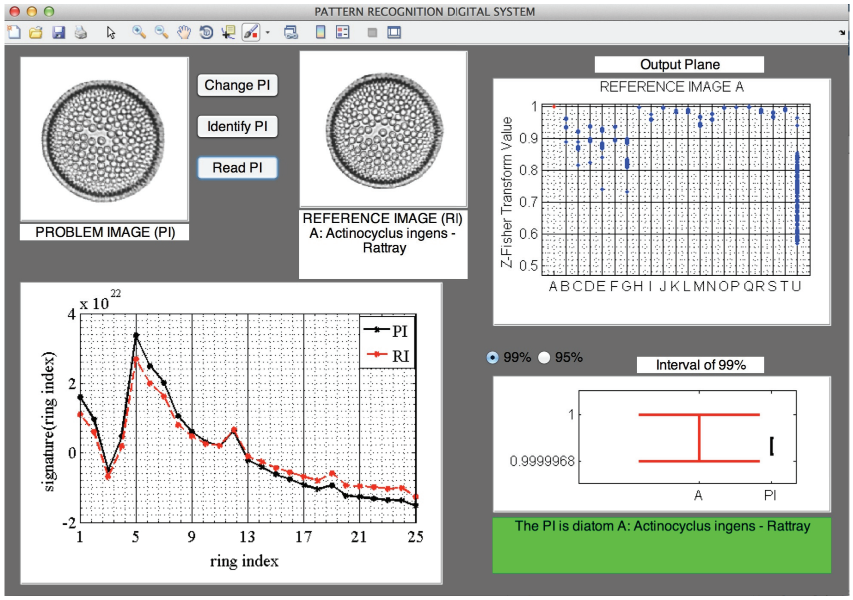

FIGURE 2. Example of the digital pattern recognition system to classify gray-scale digital images. The problem image is the same as the reference image.

Figure 2 shows the case when the digital system is used to classify diatom-fossil images. Here, the problem image is a rotated version of the reference image showing a little difference in their signature due to the sawtooth-noise. The confidence interval is given by $\rho_- = min\left\{\rho_-^\theta : 0 \le \theta \le 359\right\} = 0.9999968$ and $\rho_+ = max\left\{\rho_+^\theta : 0 \le \theta \le 359\right\} = 1$ (red colour). The confidence interval of the problem image is presented in black and it is a subinterval of $[\rho_-, \rho_+]$, this indicates that the problem image is the same as the reference image. On the other hand, when the confidence interval for a problem image is not a subinterval of the $[\rho_-, \rho_+]$, then the problem image is different that the reference image.

CONCLUSIONS

A new pattern recognition digital system was presented. The confidence intervals used to do the classification of the images were done by the Fisher's Z distribution because, in general, the data do not have a normal distribution. Here the performance of the classification system is presented using a reference image database of twenty-one gray-scale diatom-fossil digital images and 7,560 problem images to classify. The digital system has shown an excellent performance, a 99% in the classification of the diatom-fossil images. Moreover, in the presence of noise this system has a better performance than the SIFT and SURF algorithms.

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